Fracture resistance enhancement in layered composites by the interaction of two cracks – cohesive law scale effects

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Through-thickness stresses can cause initiation and propagation of interlaminar cracks, which may lead to a decrease of the structural integrity of a composite component. An example is cracks initiated at ply-drops in wind turbine blades, which can promote delamination under fatigue loading and thus significantly lower the loading capability of the loading structure. The importance of developing composite materials with high damage tolerance (high fracture resistance) will be first illustrated using specimens with multiple ply-drops tested in tension-tension fatigue. It will be shown that the delamination crack growth rate increases with the thickness of the structure, leading to increased crack growth rate as the delamination moves to the thicker section of the specimen. Thus, there is a need to apply techniques that can lead to stable crack growth or crack arrest.

A number of techniques have been developed to increase the fracture resistance of composites by making the damage prone areas stronger or tougher. This is achieved either by using tougher matrices or by modifying the fibre architecture e.g. z-pinning. Based on the early experimental evidence, an alternative approach is proposed in the present work; the fracture resistance is increased by introducing weak planes and thus allowing the initiation and propagation of multiple cracks.

First, an analytical model, based on the J-integral, will be presented to show that a linear-relationship exists between the steady-state fracture resistance and the number of cracks. The analytical model is verified by a cohesive based finite element model including two cracks and thus that it is feasible to enhance considerably the fracture resistance of a structure by adding weak layers.

The finite element model is then used to a parameter study to identify the cohesive law parameters for which the predicted linear dependency is approximately valid. It will be shown that when the distance between the two cracks is relatively small, then the overall steady state fracture resistance is almost double for a wide range of cohesive law parameters. However, in many applications there is a limit on how close the two crack can be e.g. the minimum thickness is determined by the ply thickness. The same finite element model is then used to identify the cohesive law parameters of the two cracks relatively to the material properties and height of the composite structure (scale effects) that can lead to maximum increase of the composite structure.

Approaches on how to obtain in practise interfaces with modified cohesive laws such as plasma treatment will be briefly discussed.